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(Revision of IEEE
Std 113-1973)

IEEE Guide: Test Procedures for Direct-Current Machines

Sponsor

**Rotating Machinery Committee of the
IEEE Power Engineering Society**

Secretariat

**Institute of Electrical and Electronics Engineers
National Electrical Manufacturers Association**

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Foreword

(This Foreword is not a part of IEEE Std 113-1985, IEEE Guide: Test Procedures for Direct-Current Machines.)

This standard is a revision of IEEE Std 113-1973, Test Code for Direct-Current Machines. A title change has been incorporated into the revision to be similar to other standards of this type. The title is now IEEE Guide: Test Procedures for Direct-Current Machines.

The institute wishes to acknowledge its indebtedness to those who have freely given of their time and knowledge in the preparation of this revision. Appreciation is also expressed to their employers, whose cooperation is essential in a volunteer effort such as this.

This revision was prepared and approved by a working group of the Direct-Current Machinery Subcommittee of the IEEE Rotating Machinery Committee, and at the time of this revision had the following membership:

F.T. DeWolf, *Chairman*

H.B. Hamilton	J.B. Salay	J.V. Stude
E.F. McBrien	L.A. Schlabach	V.E. Vrana
D.C. Morton	E.J. Silva	W.P. Willendrup
J.D. Raba		E.J. Woods

At the time this standard was approved, the Direct-Current Machinery Subcommittee of the IEEE Rotating Machinery Committee of the IEEE Power Engineering Society had the following membership:

E.J. Woods, *Chairman*

F.S. Buchwald	W. Lord	J.E. Radcliffe
O.C. Coho, Jr	R.E. Lordo	J.B. Salay
F.T. DeWolf	C.H. Merrifield	L.A. Schlabach
J.S. Ewing	E.H. Myers	E.J. Silva
E. Fuchs	E.P. Priebe	E.P. Smith
H.B. Hamilton		J.V. Stude

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James H. Beall, *Chairman*

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Rene Castenschiold	Irving Kolodny	Jay A. Stewart
Edward J. Cohen	George Konomos	Clifford O. Swanson
Len S. Corey	John E. May	Robert E. Weiler
Donald C. Fleckenstein	Donald T. Michael*	W.B. Wilkens
Jay Forster		Charles J. Wylie

*Member emeritus

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IEEE Guide: Test Procedures for Direct-Current Machines

WARNING: *Because of the dangerous current, voltages, and forces encountered, adequate safety precautions should be taken in all tests to avoid damage to equipment and injury to personnel. No attempt is made here to list or review the manifold general safety precautions which are well established throughout the industry. However, these test procedures do recommend special safety precautions applicable to the particular test described. All tests should be performed by knowledgeable and experienced personnel.*

The IEEE working group and committee members having voluntarily devoted time and knowledge to benefit the electrical industry in creating and revising this specification, disclaim all responsibility for its use and application.

1. Scope

These test procedures include recommendations for conducting and reporting generally acceptable tests to determine the performance characteristics of conventional direct-current machines. The tests are in two categories as described in 1.1 and 1.2.

1.1 Tests of Direct-Current Motors and Generators Designed for Essentially Ripple-Free Operation. For operation to be classed as ripple-free in accordance with this test procedure, the peak-to-peak value of the alternating component of the current shall be less than 6%, or the rms value less than 2%, of the rated current of the test machine at any of the test conditions provided that the lowest alternating frequency component of the current is 50 Hz or greater.

1.2 Tests of Direct-Current Motors Designed for Use with Rectifier Power Supplies. When a test procedure applies to a dc motor supplied with rectified power not meeting the essentially ripple-free criteria of 1.1, the procedure will be identified by the following opening statement: "On rectified power . . ."

A brief bibliography of technical papers relating to the operation of dc motors on rectified power is located in Section 8.

1.3 Other Test Procedures. It is recognized that there may be test procedures other than those described herein. When more than one procedure can be used, local conditions and the degree of precision desired will determine the procedure to be used. This guide shall not be interpreted or construed as requiring the performance of any or all of the tests herein, in any given transaction.

1.4 References

[1] ANSI C63.4-1981, American National Standard Methods of Measurement of Radio-Noise Emissions from Low-Voltage, Electrical and Electronic Equipment in the Range of 10 kHz to 1 GHz.¹

[2] ANSI/IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing.²

[3] ANSI/IEEE Std 43-1974 (R 1981), IEEE Recommended Practice for Testing Insulation Resistance of Rotating Machinery.

[4] ANSI/IEEE Std 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms.

[5] ANSI/NEMA MG1-1978, Motors and Generators.³

[6] IEEE Std 85-1973 (R 1980), IEEE Standard Test Procedure for Airborne Sound Measurements on Rotating Electric Machinery.

[7] IEEE Std 118-1978, IEEE Standard Test Code for Resistance Measurement.

[8] IEEE Std 119-1974, IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus.

¹ ANSI documents are available from the Sales Department, American National Standards Institute, 1430 Broadway, New York, NY 10018.

² IEEE documents are available from IEEE Service Center, 445 Hoes Lane, Piscataway, NJ 08854.

³ NEMA documents are available from the National Electrical Manufacturers Association, 2101 L Street, NW Washington, DC 20037.

2. Tests

2.1 General. The tests in this guide used to check the performance of direct-current machines are divided into four general categories:

- (1) Preliminary tests (see Section 4)
- (2) Performance determination tests (see Section 5)
- (3) Temperature test (see Section 6)
- (4) Miscellaneous tests (see Section 7)

The preliminary tests include not only those tests incorporated in the group of static tests (see 2.1.1), but, in addition, those tests usually conducted before the performance determination test can or should be undertaken. The performance determination tests and temperature test are those usually made to determine the performance of a direct-current machine. Miscellaneous tests are often undertaken to provide additional information pertaining to a specific dc machine.

Direct-current machines are usually tested at the point of manufacture (see 4.1.1). Certain tests from each of the four general categories are frequently incorporated into three groups of tests to serve as a guide, but these three groups do not necessarily constitute standard tests.

2.1.1 Static Test. The static test usually includes:

- (1) Resistance measurement of windings (4.2)
- (2) Air gap measurements (4.3)
- (3) Polarity and impedance drop of shunt-field coils (4.4)
- (4) Electrical resistance of insulation (cold) (4.7)
- (5) High-potential test (4.8)

2.1.2 Complete Test. See Form A. The complete test usually includes the static test (see 2.1.1) and the following tests:

- (1) Vibration (4.5)
- (2) Magnetic saturation (5.1)
- (3) Commutation (5.2)
- (4) Regulation (5.3)
- (5) Efficiency and Losses (5.4), (5.5), (5.6)
- (6) Temperature tests (6)

2.1.3 Routine Test. Routine tests are often listed in a specific standard applying to a particular type or size of dc machine. See Form B.

2.2 Alternative Methods. For many of the tests, alternative methods are described that are appropriate for the different size and types of direct-current machines and for the different conditions encountered during the test. In some cases, the preferred test method is indicated.

3. Electrical Measurements and Power Sources for All Test Procedures

3.1 Instrument Selection Factors. Either analog or digital-type instruments may be used in testing. Factors affecting accuracy, particularly with nonelectronic, analog instruments are: loading of the signal source, lead calibration, and the range, condition, and calibration of the instrument. Since instrument accuracy is generally expressed as a percent of full scale, the range of the instrument chosen should be as low as practical. The instrument should bear record of recent calibration and if extreme importance is attached to the test results the instrument should be calibrated immediately before and after the completion of the test procedure. When several instruments are connected in the circuit simultaneously, additional corrections of the instrument indication may be required.

Electronic instruments are generally more versatile and have much higher input impedances than passive (nonelectronic) types. Higher input impedance reduces the need to make corrections for the current drawn by the instrument. However, high input impedance instruments are more susceptible to noise. Common sources of noise are: inductive or electrostatic coupling of signal leads to power systems, common impedance coupling, or ground loops, inadequate common-mode rejection, and conducted interference from the power line. Good practice requires the use of shielded twisted pairs for signal leads, grounding of the shield at only one point, and keeping signal cables as far away as possible from power cables. All exposed metal parts of these instruments should be grounded for safety. Instrument calibration requirements are similar to those of nonelectronic instruments.

When suitable automatic data-acquisition systems or high-speed recorders are available they may be used provided they are suitable for the pulsating nature of the signals arising from operation on rectifier power supplies.

3.1.1 On rectified power, the average or dc values of armature and field voltages and current can be measured using permanent-magnet moving-coil (d'Arsonval) type instruments, or other instruments, including digital instrumentation known to provide true average readings. Root-mean-square values can be measured with electrodynamometer-type, iron-vane-type, or other

instrument types including digital instrumentation known to provide true rms readings. Alternating-current instruments of the type using rectifiers so as to sense only a portion of the voltage or current signal and instruments which are calibrated based on the assumption of a sinusoidal wave shape should not be used. Oscilloscope observations of the voltage and current signals are recommended to ensure that the waveforms are of the shapes to be expected. Suitably low-inductance current transducers and shielded leads should be used to minimize signal distortion and eliminate extraneous voltages.

3.1.2 The ac component of the armature and field voltages and current can be measured separately using suitable instrumentation and combined with the average value to yield the rms value of the variable. For example, the component values of the armature current are interrelated:

$$I_{rms} = \sqrt{I_{dc}^2 + I_{ac}^2}$$

where

I_{rms} = rms value of the current

I_{dc} = average value of the current

I_{ac} = rms value of the ac component of the current

If a current transformer is used to block the dc component of the current, it should be of sufficient size to avoid magnetic saturation resulting from the direct current passing through the primary winding. If a dc bias winding is used to avoid magnetic saturation of the transformer, means should be taken to restrict ac ampere turns in the bias winding to less than 2% of the ac ampere turns in the primary windings. The magnitude, wave shape, and phase relationship of the secondary current should be observed with an oscilloscope and compared with the primary current.

If a capacitor is used to block the dc component of voltage, it should be of sufficient size so that the ac voltage drop across the capacitor is less than 2% of the ac component of the voltage measured.

3.2 Voltage Measurement. Machine voltage measurements should be taken with the signal leads connected to the machine terminals. If local conditions will not permit such connections, the error introduced should be evaluated and the readings corrected.

Tests should be made at as near rated voltage as practical. If terminal voltage is slightly different from rated voltage, this difference shall be taken into account and corrections made in calculating machine characteristics.

On rectified power, the input ac voltage to the rectifier should be the specified value, +2%, -0%.

3.3 Current Measurement. Where the current to be measured is within the range of available ammeters, an ammeter may be inserted directly into the circuit. Current transducers are used when the range of available ammeters is exceeded. Also, isolation amplifiers may be used for safety purposes and to be compatible with other instrumentation. In all cases, the impedance of the ammeter or transducer shall not appreciably affect the characteristics of the machine or the circuit tested.

The current required by all protective devices used during the test shall not appreciably affect the test results. This guide recommends that these devices be so connected that a minimum of correction is necessary.

On rectified power, the rms value of the armature current or the ac component of the armature current, or both, should be measured.

3.4 Power Measurement. Electric power (watts) is usually computed as the time average of the instantaneous product of voltage and current. A direct-reading wattmeter may be used. If very high accuracy is required, corrections should be made for power loss in instruments, test connections, and protective devices.

If a calibrated driving motor or cradled dynamometer or torquemeter is used in loss measurements it should preferably be of such a size that it is loaded to at least one-third of its rating when losses for rated load are measured.

3.4.1 Input Armature-Circuit Power. On rectified power, input armature-circuit power may be measured directly using a true-reading wattmeter or other measurement means wherein the instantaneous product of voltage and current is time averaged. Alternatively, the dc and ac power components may be measured separately as described in (1) and (2) below and added together.

(1) The dc component of armature circuit power input is the product of the average input armature circuit voltage and current as measured with average-reading instruments.

(2) The ac component of the armature cir-

circuit power input is the average value of the product of the instantaneous ac components of the armature circuit voltage and current. It may be measured by blocking the dc component of either the voltage or current signals passing to the power measurement means. The precautions described in 3.1.2 relating to the fidelity of voltage and current signals apply to these signals at the power measurement means. In addition, it should be determined by simultaneous oscilloscope observations that the current and voltage signals are repetitive and precise in their phase relationship.

3.4.2 Input Shunt-Field Power. The input shunt-field power can usually be taken with sufficient accuracy as the product of the average shunt-field voltage and current. If the shunt-field current is not ripple-free as defined in 1.1 the shunt-field power shall be calculated as the product of the square of the rms value of the shunt-field current and the dc resistance.

3.5 Power Sources

3.5.1 Direct-Current Supply. The power supply should be such that a minimum of adjustment is necessary during the time test readings are taken. In general, it should be of sufficient size and in such a condition that its operation does not influence the machine under test. The power supply should be essentially ripple-free as defined in 1.1.

3.5.2 Rectified Alternating Current Supply. Performance and conformance tests on dc motors intended for service with rectifiers should be conducted using a power supply of the type resulting in the amount and frequency of current ripple for which the motor is designed. The voltage and current waveforms should be of the expected shapes and free from disturbances and instabilities. The difference between the highest and lowest peak amplitudes of the current pulses over one cycle of the fundamental frequency should not exceed 2% of the highest pulse amplitude. Significant rectifier parameters regarding armature current ripple are: number of phases and circuitry, input ac voltage and frequency, and armature circuit inductance and resistance. In the absence of rectifier facilities meeting these requirements, and when so noted on the test data record, an armature circuit power supply providing the same frequency but more current ripple than expected in service may be used and the ripple restricted to the rated value using a smoothing choke.

When so noted on the test-data record, a direct current power supply having a low-ripple voltage content, such as a dc generator, may be used to supply the shunt-field circuit power during tests using a rectifier to supply the motor armature circuit.

An indication of motor heating can be obtained from tests using dc armature power having a low-ripple content, such as a dc generator, by maintaining the armature current at the anticipated rms value in rectifier service. However, it should be recognized that machine temperatures may be higher in actual rectifier service, particularly in the case of enclosed machines. Such tests do not measure commutation performance. A low-ripple dc supply may also be used in conducting loss separation tests and in taking comparative heating and commutation tests.

4. Preliminary Tests

4.1 Reference Conditions

4.1.1 Location for Tests. Tests are usually made at the plant of the manufacturer, unless an otherwise mutually agreed upon location is established.

4.1.2 Ambient Air. Unless otherwise agreed upon, the surrounding air temperature should be between 10 °C and 40 °C, and the altitude should not exceed 1000 m (3300 ft). The procedure to be followed in the measurement of ambient temperature is given in IEEE Std 119-1974 [8]⁴.

4.1.3 Terminal Markings. Terminal markings should be in accordance with ANSI/NEMA MG1-1978 [5]. However, the manufacturers' diagram of connections should be the authority for checking terminal markings and polarities.

4.1.4 Direction of Rotation. When the direction of rotation is not specified, motors shall be tested with counterclockwise rotation and generators with clockwise rotation, when viewed from the commutator end.

4.1.5 Test Machine Rating. In these test procedures by *rated load* is meant rated load current.

4.2 Winding Resistance Measurements. The resistance of the machine windings is determined so as to check the completed winding connections.

⁴ Numbers in brackets correspond to those of the references in 1.4 of this standard.

tion, to calculate the I^2R loss, and to establish a reference resistance at a reference temperature to be used in the determination of the average temperature of the winding. (For the last of these purposes a portion of the winding may be used rather than the complete winding. See 6.3.1.2).

Resistance measurement should be made as outlined in IEEE Std 118-1978 [7]. The average temperature of the winding should be recorded at the time the cold resistance is measured. The temperature of the surrounding air shall not be regarded as the temperature of the windings, unless the machine has been standing idle under constant temperature conditions for a considerable period of time. Extreme care should be taken to secure accurate cold resistance measurements since a small error in measuring resistance will cause a comparatively large error in determining the temperature.

4.2.1 Temperature Correction of Winding Resistances. The equation to be used to correct the measured cold resistance to a common temperature standard such as 25 °C is:

$$R_1 = R_2 \frac{(k + t_1)}{(k + t_2)}$$

where

R_1 = resistance of winding (ohms) measured at cold temperature standard t_1 (°C)

R_2 = resistance of winding (ohms) measured at temperature t_2 (°C)

k = 234.5 for copper

= 225 for aluminum (EC grade based on a volume conductivity of 62%)

4.2.2 Method of Resistance Measurement. The bridge method is the preferred method. The voltage-drop method may be used as an alternate method.

4.2.2.1 Shunt-Field-Circuit Windings. The cold resistance of the shunt field shall be determined at the terminals of the shunt field with proper connections excluding all external resistances.

4.2.2.2 Armature-Circuit-Winding Resistances. The armature-circuit-winding resistance comprises the sum of the various components (excluding brush and brush-contact resistance) connected in accordance with the winding diagram of the machine. This summation should be made only after each resistance component has been corrected to a common temperature. These

components are measured as indicated below:

(1) *Armature Winding*

(a) *Method A.* This method is limited to wave-wound armatures including all two-pole rotor windings. For other winding types, or if the winding type is not known, Methods B or C given below should be used.

Using this method, the armature resistance can be determined by applying a resistance bridge across two commutator segments as near as possible to one pole pitch apart. In the case of simplex, two-pole rotor windings having an odd number of segments, one bridge contact should cover two adjacent segments. In the case of duplex windings, each bridge contact shall cover two adjacent segments.

(b) *Method B (Preferred).* A suitable low-resistance harness should be connected to the rotor winding either at the risers or end clips or on the commutator segments so as to contact the rotor winding at each brush location. For a simplex winding the harness should contact one commutator segment per pole spaced one pole pitch apart. In the case of nonintegral spacing, the contact may be made to two adjacent commutator segments simultaneously. For a duplex rotor winding the harness should contact two adjacent commutator segments simultaneously at each brush position. In case the rotor winding type is not known, a close approximation to the winding resistance may be attained by connecting the harness as described for a duplex winding or Method C may be applied.

The resistance measured by connecting the bridge between the terminal legs of this harness simulating the positive and negative brushes is considered as the rotor winding resistance. Care shall be taken to reduce the contact resistance to a negligibly low value.

(c) *Method C (Alternate).* This is the voltage-drop method of measuring the armature resistance. The brush rigging should be properly assembled. The brush fit should be good (see 4.6.1). The rotor should be suitably blocked to prevent rotation. The brush rigging should be used as the current connection and the potential drop measured as follows: The two potential leads should be applied to the commutator segments approximately one pole pitch apart. These leads should be located on segments as near the center of the brush contact surface as possible. The potential leads should be shifted and readings recorded for each pole pitch. The current shall be maintained constant for all of these

measurements. The current should not exceed 10% of the rated value. The resistances shall be computed from the average of all of the potential-drop readings and the circulating current. Usually this will give a lower value of resistance than the value measured using Methods A or B.

CAUTION: *The current and the time it is applied shall be limited to prevent damage to the commutator due to local heating from this circulating current.*

(2) *Commutating-Field Winding.* On uncompensated machines, the resistance of this winding may be measured directly at its terminals. If one end of the winding is permanently connected to the brush rigging, the commutating field resistance should be measured between this point and the outside terminal. On machines that are compensated, this winding may be interleaved with the compensating-field winding (pole-face winding). In such designs the combined resistance of these two windings should be measured.

If the windings are split and located electrically on opposite sides of the armature or arranged in some other manner, the resistance of each winding component should be measured individually.

(3) *Compensating-Field Windings.* If separate from commutating-field windings, the resistance should be measured at the terminals of this winding.

(4) *Series-Field Windings.* The resistance should be measured at the terminals of all distinct windings. If the winding is permanently connected to one of the other stationary windings and with only one distinct connection strap between the two windings, the series-field resistance should be measured between the terminal and this distinct connection strap. If the series-field winding is interleaved, or does not have a distinct connection between windings, then its resistance should be measured in combination with the other stator windings to which it is interconnected.

(5) *Shunts.* The resistance of any shunts connected in parallel with the machine windings should be measured at the cable terminals of the shunt. The shunts shall be disconnected from the windings when measuring the winding and shunt resistances. The windings shunted by these various resistors should be identified with the resistance of the shunts.

(6) *Auxiliary Windings and Associated Series*

Resistors. The resistance of all auxiliary windings should be measured at the terminals. The resistance of all auxiliary winding adjusting resistors should be measured at the terminals of the cables which join these resistors to the winding. In addition to the resistance, the connections of all adjusting resistors should be recorded.

4.3 Air Gap Measurements. The measurement of the air gaps should include a check of correct installation of main poles, test of possible deformation of bearing or bearing support, inspection for sufficient clearance before testing, and proper assembly of rotor with respect to stator. Dissymmetry in main- or commutating-field pole air gaps may cause difficulties such as excessive voltage ripple or overheating of equalizers.

Measure the minimum air gap beneath the center (approximately) of each main pole and each commutating-field pole piece using a suitable feeler gage or tapered gage to determine the gap to at least the nearest 0.100 mm (0.005 in) for integral-horsepower motors and to the nearest 0.050 mm (0.002 in) for fractional-horsepower motors. All measurements should be made between iron surfaces of the pole pieces and the rotor. In normal practice, a common point on the rotor is selected and the point is rotated to each pole in turn as measurements are made.

Where apertures are not provided, the uniformity of the air gap can be determined by ascertaining that the rotor turns freely in the assembled machine when wound with a wire spaced spirally around the rotor periphery. For this test the diameter of the wire should be at least 70% of half the difference between the diametric distance of the main pole faces and the outside diameter of the rotor.

4.3.1 Data Record. This procedure recommends uniformity in pole identification. Main pole No 1 and commutating-field pole No 1 shall be either the top pole or the first pole of each kind in a clockwise direction from the vertical centerline above the horizontal centerline when the machine is viewed from the commutator end. Each main pole will be numbered starting with pole No 1 and proceeding consecutively in a clockwise direction.

For a machine with a vertical shaft, the No 1 pole is the first one in a clockwise direction as viewed from the commutator end of the machine from some designated point such as the nameplate or direction of rotation mark. This point should be identified on data record.

4.4 Polarity and Impedance Drop of Field Coils.

4.4.1 Polarity. The polarity of the various field windings may be determined by any of the methods indicated below. Each field-winding polarity should be ascertained independently.

Polarity may be checked by means of a compass while passing current through all of one type of field coils connected in series or by observing the attraction or repulsion between the ends of two short, soft-iron bars bridging between adjacent pole tips.

Field coils that are constructed of large size conductors that may be easily traced throughout the winding may have their polarity checked by tracing the winding and applying the right-hand rule.

4.4.2 Impedance Drop. Since a dc resistance test is apt to be insensitive to the detection of variations among the field coils, an ac impedance drop test is recommended. A coil having shorted turns will be indicated by a low impedance when compared to that of the other coils.

4.5 Vibration. Motor vibration caused by mechanical or electromagnetic dissymmetry should be measured using a low ripple source of direct current such as a generator. Such measurements are usually made at no load and at rated speed using a half-key in the shaft extension. The frequency of vibration is related to the speed of rotation.

On rectified power, in addition to vibration caused by mechanical or electromagnetic dissymmetry, vibrations may be experienced related to the amplitude and frequency of the ripple components of armature and field current. The power supply used should be in accordance with 3.5.2. Tests should be conducted at various loads over the entire speed range of the machine including speed control by armature voltage where applicable. To differentiate between vibration due to current ripple and that due to slot ripple or other factors, the vibration frequencies should be examined as the speed of rotation is changed slowly. Natural frequencies of machine mechanical parts may be excited by power supply frequencies, harmonics, or sub-harmonics acting independently or reinforced by slot ripple. Also, measurements can be made with varying degrees of current ripple as accomplished by the use of a smoothing reactor or by using a low ripple power supply, such as a dc generator. Vibration

velocity is the recommended measurement quantity.

Radially- and axially-directed vibration measurements should be made at the machine bearing housing. If the bearing housings are not accessible the readings should be taken at the housing support as near the housing as possible.

Mounting conditions will affect the vibration of the machine. Machines provided with self-supporting bases, or of the end-shield type construction, may be mounted in such a manner as to make them independent of mounting conditions. On large machines this becomes impractical and experience has shown it to be unnecessary. To obtain measurements that are as nearly as possible independent from mounting conditions, the machine should be placed on flexible pads or springs. These should compress by the weight of the machine alone, in amounts not less than the values shown below.

Speed (r/min)	Minimum Compression (mm)	Minimum Compression (in)
7200	0.4	$\frac{1}{64}$
3600	1.5	$\frac{1}{16}$
1800	6	$\frac{1}{4}$
1200	15	$\frac{9}{16}$
900	25	1
720	40	$1\frac{9}{16}$
600	55	$2\frac{1}{4}$

The value for minimum compression at other speeds may be determined from the equation:

$$c = \left(\frac{k}{v} \right)^2$$

where

$k = 4500$ for c (millimeters)

900 for c (inches)

$v =$ speed (r/min)

The pads or springs should be selected so that the compression is not more than one-half of the unloaded thickness.

4.6 Brush Setting. The best brush position for good commutation and the desired voltage or speed characteristics of generators or motors, respectively, shall be determined by observation of the machines under load. The manufacturer of